

APPARATUS AND METHODS FOR TREATING TISSUE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of U.S. Patent Application Serial No. 09/898,726 filed July 3, 2001, which is a continuation-in-part of U.S. Patent Application Serial No. 09/602,436 filed June 23, 2000, which in turn claims benefit from U.S. Provisional Patent Application Serial No. 60/141,077 filed June 25, 1999, each being incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

[0002] The present invention relates to treatment of tissue. More particularly, the present invention provides methods and apparatus for treating valvular disease with a catheter inserted into a patient's cardiac chambers, the catheter having an end effector for modifying cardiac structures, including valve leaflets and support structure.

BACKGROUND OF THE INVENTION

[0003] Degenerative valvular disease is the most common cause of valvular regurgitation in human beings. Regurgitation is typically characterized by an expanded valve annulus or by lengthened chordae tendineae. In either case, an increase in the geometry of a valve or its supporting structure causes the valve to become less effective, as it no longer fully closes when required.

[0004] Loose chordae tendineae may result, for example, from ischemic heart disease affecting the papillary muscles. The papillary muscles attach to the chordae tendineae and keep the leaflets of a valve shut. Some forms of ischemic cardiac disease cause the papillary muscles to lose their muscle tone, resulting in a loosening of the chordae tendineae. This loosening, in turn, allows the leaflets of the affected valve to prolapse, causing regurgitation.

[0005] It therefore would be desirable to provide methods and apparatus for treatment of tissue that modify the geometry and operation of a heart valve.

[0006] It would also be desirable to provide methods and apparatus that are configured to thermally treat chordae tendineae, the annulus of a valve, or valve leaflets.

[0007] It would also be desirable to further provide methods and apparatus that are configured to mechanically modify the geometry and operation of a heart valve and annulus of a valve either alone or in addition to thermal treatment.

SUMMARY OF THE INVENTION

[0008] In view of the foregoing, it is an object of the present invention to provide methods and apparatus for the treatment of tissue that modify the geometry and operation of a heart valve.

[0009] It is another object of the present invention to provide methods and apparatus that are configured to thermally treat chordae tendineae, the annulus of a valve, or valve leaflets.

[0010] It is another object of the present invention to further provide methods and apparatus that are configured to mechanically modify the geometry and operation of a heart valve and annulus of a valve either alone or in addition to thermal treatment.

[0011] These and other objects of the present invention are accomplished by providing apparatus and methods for thermally or mechanically treating tissue, such as valvular structures, to reconfigure or shrink the tissue in a controlled manner, thereby improving or restoring tissue function. Embodiments of the present invention advantageously may be employed to modify flow regulation characteristics of a cardiac valve or its component parts, as well as to modify flow regulation in other lumens of the body, including, for example, the urinary sphincter, digestive system valves, leg vein valves, etc., where thermal shrinkage or mechanical reconfiguration of tissue may provide therapeutic benefit.

[0012] In a first family of embodiments of the present invention, apparatus is provided having an end effector that induces a temperature rise in an annulus of tissue surrounding the leaflets of a valve sufficient to cause shrinkage of the tissue, thereby reducing a diameter of the annulus and causing the valves to close

more tightly. In a second family of embodiments, apparatus is provided having an end effector that selectively induces a temperature rise in the chordae tendineae sufficient to cause a controlled degree of shortening of the chordae tendineae, thereby enabling the valve leaflets to be properly aligned. In yet a third family of embodiments, apparatus is provided having an end effector comprising a mechanical reconfigurer configured to attach to a longitudinal member, such as the chordae tendineae. The reconfigurer forces the longitudinal member into a tortuous path and, as a result, reduces the member's effective overall or straight length.

[0013] Any of these embodiments may employ one or more expanding members that serve to stabilize the end effector in contact with the tissue or structure to be treated. In addition, where it is desired to preserve the interior surface of a lumen or structure, the instrument may include means for flushing the surface of the tissue with cooled saline. Where it is desired to achieve a predetermined degree of heating at a depth within a tissue or structure, the end effector may comprise a laser having a wavelength selected to penetrate tissue to the desired depth, or the end effector may comprise a plurality of electrically conductive needles energized by an RF power source, as is known in the electrosurgical arts. The end effector may alternatively comprise an acoustic heating element, such as an ultrasonic transducer.

[0014] In another aspect of the present invention, mechanical clips may be provided preferably made from shape memory alloys or superelastic alloys, e.g., Nickel-Titanium alloy (nitinol). Such clips may be delivered to the valve and annulus of tissue surrounding the valve in a variety of ways, e.g., intravascularly, endoscopically, or laparoscopically, either after the thermal treatment described above, or without the thermal treatment. During delivery by, e.g., a catheter, the clips may be compressed into a smaller configuration to facilitate transport. Upon exiting the catheter, the clips preferably expand to a second configuration for attachment to the valve tissue. The clips may be attached to the annulus of tissue surrounding the valve upon being urged out of the catheter distal end; they may be attached to opposing sides of the valve and preferably have a compressive spring

force to draw or cinch the sides of the valve towards one another. The clips may be configured to traverse directly over the valve itself, but they are preferably configured to lie partially over the periphery of the valve to prevent obstruction of the valve channel. A central region of the clips may be formed in a variety of geometric shapes, e.g., semi-circles, arcs, half-ellipses, triangles, rectangles, and loops. Aside from clips, expandable meshes and grids may also be used to draw or cinch the valve edges together.

[0015] Moreover, the clips may be coated with therapeutic drugs, which may be time-released, or they may also be coated at least partially with a radiopaque coating to aid in visualization during implantation.

[0016] Delivery catheters which may be used to deliver the clips may also incorporate sensors or energy delivery devices, e.g., transducers, on the distal ends. For example, they may be configured as a sensor to measure properties, e.g., ultrasound, Doppler, electrode, pressure sensor or transducer, etc., of the tissue prior to catheter withdrawal. Such sensors may also be used to measure properties such as flow rates, pressure, etc. for measurement pre-treatment and post-treatment. Alternatively, they may also be used as a transducer to deliver energy, e.g., RF, electrical, heat, etc., to the affected tissue or the surrounding area by, e.g., either as a separate device or directly through the clip itself.

[0017] Methods of using apparatus according to the present invention are also provided.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] The above and other objects and advantages of the present invention will be apparent upon consideration of the following detailed description, taken in conjunction with the accompanying drawings, in which like reference numerals refer to like parts throughout, and in which:

[0019] FIG. 1 is a side-sectional view of a human heart showing major structures of the heart, including those pertaining to valvular degeneration;

[0020] FIG. 2 is a side view of apparatus of a first family of embodiments constructed in accordance with the present invention;

[0021] FIGS. 3A-3C are, respectively, a side view of an end effector for use with the apparatus of FIG. 2 and a sectional view through its catheter along sectional view line A-A, a side view of an alternative end effector and a sectional view of its catheter along view line B-B, and a side view of a still further alternative end effector;

[0022] FIG. 4 is a sectional view through the human heart, depicting a method of using the apparatus of FIG. 2 to shrink tissue in an annulus surrounding the leaflets of a regurgitating valve;

[0023] FIGS. 5A and 5B are schematic views of alternative embodiments of the apparatus of FIG. 2;

[0024] FIGS. 6A-6D are views of a still further alternative embodiment of the apparatus of FIG. 2 having barbs, and illustrating a method of use;

[0025] FIGS. 7A-7C are schematic views showing, respectively, an alternative embodiment of the end effector of FIGS. 6 having electrically insulated barbs, a method of using the end effector to thermally treat tissue, and a temperature profile within the tissue during treatment;

[0026] FIGS. 8A and 8B are side views of another alternative embodiment of the apparatus of FIG. 6 having multipolar, individual electrodes;

[0027] FIG. 9 is a side view of an alternative embodiment of the apparatus of FIG. 8 having individual ultrasonic transducers;

[0028] FIG. 10 is a side-sectional view of another alternative embodiment of the apparatus of FIG. 8 having individual laser fibers;

[0029] FIG. 11 is a side-sectional view of an alternative embodiment of the apparatus of FIGS. 8-10 having individual barb members that may comprise multipolar electrodes, ultrasonic transducers, or laser fibers;

[0030] FIG. 12 is a sectional view through the human heart, illustrating an alternative method of introducing apparatus of the first family of embodiments to a treatment site;

[0031] FIGS. 13A and 13B are views of an alternative embodiment of the apparatus of FIG. 2 shown, respectively, in schematic side view and in use shrinking an annulus of tissue;

[0032] FIGS. 14A and 14B are, respectively, a side view of an alternative embodiment of the apparatus of FIG. 2, and a method of using the embodiment via the introduction technique of FIG. 12;

[0033] FIGS. 15A and 15B are isometric views of an alternative end effector for use with the apparatus of FIGS. 14;

[0034] FIG. 16 is a top view of apparatus of a second family of embodiments constructed in accordance with the present invention;

[0035] FIG. 17A-17C are views of end effectors for use with the apparatus of FIG. 16;

[0036] FIG. 18 is a sectional view of the human heart, illustrating a method of using the apparatus of FIG. 16 to selectively induce a temperature rise in the chordae tendineae sufficient to cause a controlled degree of shortening of the tendineae;

[0037] FIGS. 19A-19C show a section of chordae tendineae and illustrate a method of shrinking the tendineae in a zig-zag fashion using the end effector of FIG. 17C with the apparatus of FIG. 16;

[0038] FIGS. 20A-20C show, respectively, a side view of an intact tendineae, a side view of the tendineae after treatment by a shrinkage technique, and a cross section through the tendineae along sectional view line C-C of FIG. 20A after treatment by an alternative shrinkage technique;

[0039] FIGS. 21A and 21B are side views of apparatus of a third family of embodiments, constructed in accordance with the present invention, shown in a collapsed delivery configuration and in an expanded deployed configuration;

[0040] FIGS. 22A and 22B are schematic views depicting a method of using the apparatus of FIGS. 21 to mechanically shorten an effective length of chordae tendineae; and

[0041] FIG. 23 is a side view, partially in section, illustrating a method and apparatus for non-invasive coagulation and shrinkage of scar tissue in the heart, or shrinkage of the valve structures of the heart.

[0042] FIG. 24A is an isometric view of a variation on a valve resizing device as an expandable grid with anchoring ends.

[0043] FIG. 24B is a top view of another variation on the valve resizing device as an expandable mesh.

[0044] FIGS. 25A and 25B are side views of exemplary anchors which may be used with a valve resizing device.

[0045] FIG. 26 is a cross-sectional superior view of a heart section with the atrial chambers removed for clarity with the device of FIG. 24A implanted over a valve.

[0046] FIGS. 27A and 27B are a top view showing variations on a circumferential clip.

[0047] FIG. 28 is a cross-sectional superior view of a heart section with the atrial chambers removed for clarity with the device of FIG. 27A implanted around a valve.

[0048] FIGS. 29A and 29B show a side view and an end view, respectively, of a variation on a clip.

[0049] FIGS. 30A and 30B show a side view and an end view, respectively, of another variation on a clip.

[0050] FIGS. 31A-31D show a top, side, end, and isometric view, respectively, of a further variation on the clip.

[0051] FIGS. 32A-36B show top and side views of alternative variations on the clip.

[0052] FIG. 37 shows a cross-sectional view of a variation on the distal section of a delivery catheter.

[0053] FIG. 38 shows a cross-sectional view of another variation on the distal section of a delivery catheter where the clip is held in a different configuration.

[0054] FIG. 39 shows a cross-sectional view of yet another variation on the distal section of a delivery catheter.

[0055] FIGS. 40A and 40B are top and side views of a variation on a handle for controlling the advancement of the clip.

[0056] FIGS. 41A and 41B illustrate a cross-sectional view of a heart and a possible method of delivering and implanting a clip over the heart valve.

[0057] FIG. 41C is a cross-sectional view of a heart and a variation on the delivery catheter having a sensing device or a transducer integrated on the distal end.

[0058] FIGS. 42A-42D are cross-sectional superior views of a heart section with the atrial chambers removed showing an alternative method of delivering and implanting clips through the coronary sinus.

[0059] FIGS. 43A and 43B are a superior view and a side view of a valve, respectively, showing an alternative clip configuration implanted on the valve.

DETAILED DESCRIPTION OF THE INVENTION

[0060] With reference to FIG. 1, a sectional view through human heart **H** is presented. Major structures labeled include the right atrium **RA**, left atrium **LA**, right ventricle **RV**, left ventricle **LV**, superior vena cava **SVC**, inferior vena cava **IVC**, and ascending aorta **AA**. Structures that may be involved in valvular degeneration and regurgitation are also labeled, including the papillary muscles **PM**, chordae tendineae **CT**, valve leaflets **L**, and annuluses of tissue surrounding the leaflets **A**, as well as the tricuspid valve **TV**, the bicuspid or mitral valve **MV**, and the aortic valve **AV**. The pulmonary valve **PV** is not seen in the cross section of FIG. 1, but may also experience valvular degeneration. As discussed previously, degenerative valvular disease often leads to valvular regurgitation, which is typically characterized by an expanded valve annulus **A** or by lengthened chordae tendineae **CT**. Loose chordae tendineae may result from ischemic heart disease affecting the papillary muscles **PM**, which attach to the chordae tendineae and act to regulate flow through leaflets **L**.

[0061] The present invention therefore provides apparatus and methods for shrinking or reconfiguring tissue, such as annulus **A** or chordae tendineae **CT**. The present invention also encompasses optionally altering a shape of the valve through mechanical attachments. The mechanical attachments, as discussed in detail below, may be done either after the shrinking or reconfiguring of the tissue, or it may be done as a stand-alone procedure. Embodiments of the present invention advantageously may be employed to modify flow regulation

characteristics of a cardiac valve or its component parts, as well as to modify flow regulation in other lumens of the body, including, for example, the urinary sphincter, digestive system valves, leg vein valves, etc., where thermal shrinkage or mechanical reconfiguration of tissue may provide therapeutic benefit.

[0062] Figures 2-15 illustrate apparatus of a first family of embodiments of the present invention. The first family of embodiments have an end effector that induces a temperature rise in an annulus of tissue surrounding the leaflets of a valve sufficient to cause shrinkage of the tissue, thereby reducing a diameter of the annulus and causing the valve to close more tightly.

[0063] Referring to FIG. 2, apparatus 30 comprises catheter 32 having end effector 34 in a distal region of the catheter. End effector 34 may be collapsible within and extendable beyond the distal end of catheter 30 to permit percutaneous delivery to a treatment site. End effector 34 has an annular shape to facilitate treatment of an annulus of tissue, as well as stabilization against the walls of a treatment site.

[0064] With reference to FIGS. 3A-3C, alternative embodiments of end effector 34 and catheter 32 are described. In FIG. 3A, end effector 34 comprises expandable balloon 40. Balloon 40 comprises bipolar electrodes 42a and 42b that may be attached to a radiofrequency ("RF") voltage or current source (not shown). Balloon 40 further comprises lumen 44 to facilitate unimpeded blood flow or fluid transport therethrough, and temperature sensors 46 to monitor shrinkage of tissue caused by current flow between bipolar electrodes 42a and 42b. Sensors 46 may comprise, for example, standard thermocouples, or any other temperature sensor known in the art.

[0065] The end effector of FIG. 3A is thus capable of achieving controlled luminal shrinkage while allowing blood to pass through the center of balloon 40. Electrodes 42a and 42b are disposed as bands on the periphery of balloon 40 and may inject an RF electrical current into the wall of a treatment site, such as an annulus or lumen, to shrink collagen contained therein. Furthermore, balloon 40 may be inflated with a circulating coolant C, such as water, to cool the surface of balloon 40 and thereby minimize thermal damage at the surface of the treatment

site. Thermally damaged tissue may be thrombogenic and may form thrombus on its surface, leading to potentially lethal complications.

[0066] FIG. 3A also provides a cross section through an embodiment of catheter 32, along sectional view line A-A, for use in conjunction with the balloon embodiment of end effector 34. Catheter 32 comprises coolant lumens 48a and 48b that may circulate coolant C into and out of balloon 40, respectively. It further comprises wires 49a-49c, electrically coupled to electrode 42a, electrode 42b, and temperature sensors 46, respectively.

[0067] In FIG. 3B, an alternative embodiment of end effector 34 and catheter 32 is presented. Instead of RF energy, the heating element in this embodiment is a laser source (not shown) coupled to fiber optic cable 50 having side firing tip 51. The laser source injects light energy into the wall of a treatment site via fiber optic cable 50, thereby thermally shrinking the tissue. The wavelength of the laser may be selected to penetrate tissue to a desired depth. Furthermore, a plurality of fiber optic cables 50, coupled to the laser source and disposed about the circumference of balloon 40, may be provided.

[0068] Balloon 40 is substantially transparent to the laser energy, and coolant C may again serve to cool the surface of balloon 40, thereby minimizing damage at the surface of the treatment site. The circulating stream of coolant C maintains the temperature of surface tissue layers at a sufficiently low level to prevent thermal damage, and thus, to prevent formation of thrombus. Temperature sensor 46 optionally may also be provided.

[0069] As seen in FIG. 3C, end effector 34 may alternatively comprise wrapped sheet 52 incorporating one or more electrodes on its surface. Sheet 52 may be advanced to a treatment site in a collapsed delivery configuration within a lumen of catheter 32, and may then be unfurled to an expanded deployed configuration wherein it contacts the interior wall of the treatment site and may be energized to shrink tissue.

[0070] Referring now to FIG. 4, a method of using apparatus 30 to thermally shrink an annulus of tissue is described. End effector 34 is placed in intimate contact with the inner wall of a blood vessel or other body lumen. In the

valvular regurgitation treatment technique of FIG. 4, end effector 34 is percutaneously delivered just proximal of aortic valve AV within ascending aorta AA at annulus of tissue A supporting leaflets L, using well-known techniques. Aortic valve AV suffers from valvular degeneration, leading to regurgitation. End effector 34 delivers energy to annulus A sufficient to heat and shrink the annulus, thus enhancing function of the degenerative valve.

[0071] Collagen within annulus A shrinks and reduces a diameter of the annulus. Leaflets L are approximated towards one another, as seen in dashed profile in FIG. 4, and valvular regurgitation is reduced or eliminated. In addition to valvular regurgitation, the technique is expected to effectively treat aortic insufficiency.

[0072] End effector 34 stabilizes apparatus 30 against the wall of a body passageway. Once stabilized, a source of energy may be applied to the wall to thermally shrink the tissue contained in the wall. In addition to the application of FIG. 4, treatment may be provided, for example, to the annulus of mitral valve MV, to the urinary sphincter for treatment of incontinence, to digestive system valves for treatment of acid reflux, to leg vein valves, and to any other annulus of tissue where treatment is deemed beneficial.

[0073] With reference to FIGS. 5A and 5B, alternative embodiments of the apparatus of FIG. 2 are described. In FIG. 5A, apparatus 60 comprises catheter 62 having a lumen, in which end effector 64 is advanceably disposed. End effector 64 comprises monopolar electrode 66, which is fabricated in an arc from a shape memory alloy, such as spring steel or nitinol, to approximate the shape of an annulus of tissue at a treatment site within a patient. Electrode 66 may be retracted within the lumen of catheter 62 to facilitate transluminal, percutaneous delivery to the treatment site. Once in position, electrode 66 may be advanced out of a distal region of catheter 62. The electrode resumes its arc shape and approximates the wall of the treatment site.

[0074] Monopolar electrode 66 is electrically coupled to RF source 68, which is positioned outside of the patient. RF source 68 is, in turn, coupled to reference electrode 69. When RF source 68 is activated, current flows between

monopolar electrode 66 and reference electrode 69, which may, for example, be attached to the exterior of the patient in the region of the treatment site. RF current flows into the wall of the treatment site, thereby effecting annular tissue shrinkage, as described previously.

[0075] In FIG. 5B, a bipolar embodiment is provided. Apparatus 70 comprises catheter 72 and end effector 74. End effector 74 comprises a plurality of atraumatic tipped legs 76 that are electrically coupled by a plurality of current carrying wires 78 to an RF source (not shown). The plurality of legs contact the wall of a treatment site and inject current into the wall. The current flows between the tips of the legs. Alternatively, the plurality of legs may comprise a monopolar electrode coupled by a single wire to the RF source, and current may flow between the plurality of legs and a reference electrode, as in FIG. 5A.

[0076] Referring to FIGS. 6A-6D, another alternative embodiment of the apparatus of FIG. 2 is described. FIG. 6A shows apparatus 80 in side-sectional view in a retracted delivery configuration. Apparatus 80 comprises catheter 82 and end effector 84. Catheter 82 further comprises central bore 86, a plurality of side bores 88, and optional temperature sensors 90. End effector 84 may, for example, be fabricated from nitinol or spring steel, and comprises conductive shaft 92 having a plurality of radially extending electrodes 94 with optional barbs 96. Conductive shaft 92 is electrically coupled to RF source 98, which is electrically coupled to reference electrode 99. Conductive shaft 92 is disposed within central bore 86, while electrodes 94 are disposed within side bores 88.

[0077] End effector 84 is advanceable with respect to catheter 82. When advanced distally, apparatus 80 assumes the expanded deployed configuration of FIG. 6B, wherein electrodes 94 extend through side bores 88 beyond the surface of catheter 82. Apparatus 80 is also configured such that its distal region may approximate the shape of an annulus of tissue, as described hereinbelow with respect to FIG. 6D, and is thus suited for both linear and circular subsurface tissue coagulation and shrinkage.

[0078] FIGS. 6C and 6D provide a method of using apparatus 80 to treat annulus of tissue A surrounding a heart valve. Apparatus 80 is percutaneously

advanced to the surface of a heart valve in the delivery configuration of FIG. 6C. Once positioned at annulus A, the distal region of apparatus 80 approximates the shape of the annulus, as seen in FIG. 6D. This may be accomplished, for example, with a steering mechanism comprising two purchase points or a pre-shaped tip that is retracted within a straight guiding catheter to allow insertion into the vascular system, as described in U.S. Patent No. 5,275,162, which is incorporated herein by reference. Once inserted, the pre-shaped tip is advanced out of the guide catheter and recovers its preformed shape.

[0079] With apparatus 80 approximating annulus A, end effector 84 is distally advanced with respect to catheter 82, thereby selectively advancing electrodes 94 into the annulus. RF source 98 then provides RF current, which flows between electrodes 94 and reference electrode 99. The annulus of tissue shrinks, bringing valve leaflets into proper position and minimizing or eliminating regurgitation through the valve.

[0080] Catheter 82 insulates conductive shaft 92 from annulus A, thereby protecting surface tissue and only allowing coagulation at depth in treatment zones surrounding electrodes 94. To further ensure that coagulation only occurs at depth, a coolant, such as saline, may be introduced through central bore 86 and side bores 88 of catheter 82 to the surface of annulus A, thereby cooling and flushing the area where electrodes 94 penetrate the tissue. It is expected that such liquid infusion will keep the surface of the annulus clean and will prevent thrombus formation in response to thermal damage.

[0081] Referring now to FIG. 7A-7C, an alternative embodiment of end effector 84 of FIGS. 6 is described. The end effector of FIGS. 7 is equivalent to the end effector of FIGS. 6 except that it is coated with electrically insulating layer I. Insulation layer I covers the entire exterior of end effector 84, except at the distal ends of the plurality of electrodes 94. The layer is preferably sufficiently thin to allow insertion of electrodes 94 into tissue T without impediment. The exposed distal ends of the electrodes are configured to deliver energy into subsurface tissue at treatment zones Z. The zones may be ideally

modeled as spheres of subsurface tissue. Tissue shrinks within treatment zones **Z** without damaging surface tissue, as seen in FIG. 7B.

[0082] The size of treatment zones **Z** may be controlled to ensure that tissue remodeling only occurs at depth. Assuming a temperature T_1 , at which tissue damage is negligible, the magnitude of current passed through tissue **T** may be selected (based on the material properties of the tissue and the depth of insertion of electrodes 94 within the tissue) such that the temperature decays from a temperature T_0 at a position D_0 at the surface of an electrode 94 to the benign temperature T_1 at a distance D_1 from the surface of the electrode. The distance D_1 may be optimized such that it is below the surface of tissue **T**. An illustrative temperature profile across a treatment zone **Z** is provided in FIG. 7C.

[0083] With reference to FIGS. 8A and 8B, another alternative embodiment of the apparatus of FIG. 6 is described. Apparatus 100 comprises catheter 102 and end effector 104. End effector 104 further comprises a plurality of individual, multipolar electrodes 106, which are electrically coupled to an RF or other current source (not shown) by a plurality of current carrying wires 108. As with the embodiments of FIGS. 6 and 7, apparatus 100 is configured such that end effector 104 may approximate an annulus, as seen in FIG. 8B.

[0084] Referring to FIGS. 9-11, alternative embodiments of the apparatus of FIGS. 8 are described. In FIG. 9, apparatus 110 comprises catheter 112 and end effector 114. End effector 114 comprises a plurality of acoustic heating elements 116. Acoustic elements 116 may, for example, comprise ultrasonic transducers. The acoustic energy may further be focused by appropriate means, for example, by lenses, such that a tissue damage threshold sufficient to cause shrinkage is only attained at a specified depth within treatment site tissue, thereby mitigating surface tissue damage and thrombus formation. Acoustic elements 116 are connected to appropriate controls (not shown). Apparatus 110, and any other apparatus described herein, may optionally comprise temperature sensors 118.

[0085] In FIG. 10, apparatus 120 comprises catheter 122 and end effector 124. Catheter 122 comprises a plurality of central bores 126 and a plurality of side bores 128, as well as a plurality of optional temperature sensors 130. End

effector 124 comprises a plurality of side-firing fiber optic laser fibers 132 disposed within central bores 126 of catheter 122. The fibers are aligned such that they may deliver energy through side bores 128 to heat and induce shrinkage in target tissue. Fibers 132 are coupled to a laser source (not shown), as discussed with respect to FIG. 3B. Suitable wavelengths for the laser source preferably range from visible (488-514 nm) to infrared (0.9-10.6 microns), wherein each wavelength has an ability to heat tissue to a predetermined depth. As an example, a preferred laser source comprises a continuous wave laser having a 2.1 micron wavelength, which will shrink and heat tissue to a depth of 1-2 mm.

[0086] In FIG. 11, apparatus 140 comprises catheter 142 and end effector 144. Catheter 132 comprises central bores 146 and side bores 148. Catheter 132 further comprises temperature sensors 150 that are configured to penetrate superficial tissue layers to measure temperature at depth. Temperature sensors 150 may be retractable and extendable to facilitate percutaneous delivery of apparatus 140. End effector 144 comprises fibers 152 disposed within central bores 146. Fibers 152 are retractable within and extendable beyond side bores 148. Fibers 152 are preferably sharpened to facilitate tissue penetration and energy delivery to subsurface tissue, thereby inducing shrinkage of the tissue.

[0087] Fibers 152 may comprise any of a number of energy delivery elements. For example, fibers 152 may comprise a plurality of optical fibers coupled to a laser (not shown). The wavelength of the laser may be selected as described hereinabove, while the energy deposited by the fibers may be controlled responsive to the temperature recorded by sensors 150. Thus, for example, a controller (not shown) may be provided to switch off the laser once a preset temperature, for example, 45°C-75°C, is attained, thereby ensuring that a sufficiently high temperature is achieved to cause tissue shrinkage without inadvertently damaging surrounding tissues.

[0088] Fibers 152 may alternatively comprise a plurality of multipolar electrodes. Each electrode may be capable of injecting RF energy into tissue independently. Alternatively, current may be passed between a pair of adjacent or non-adjacent electrodes to heat intervening tissue.

[0089] Referring now to FIG. 12, an alternative method of introducing apparatus of the first family of embodiments to a treatment site is described. Apparatus 30 of FIG. 2 is been introduced to the annulus of tissue A surrounding mitral valve MV via the venous circulatory system. Catheter 32 is transluminally inserted via the jugular vein and superior vena cava SVC. The distal end of the catheter or a separate instrument then penetrates atrial septum AS using a procedure known as septostomy. Once the septum is perforated, end effector 34 may be inserted into left atrium LA and positioned over mitral valve annulus A to effect the thermal treatment described hereinabove. The tricuspid valve in the right ventricle, and the pulmonic valve, may also be treated in the same manner using a venous approach.

[0090] Referring to FIGS. 13A and 13B, a further alternative embodiment of the apparatus of FIG. 2 is described that may be introduced using the technique of FIG. 4, the technique of FIG. 12, or by another suitable technique. Apparatus 160 comprises catheter 162 and end effector 164. End effector 164 comprises adjustable, heatable loop 166, which is configured for dynamic sizing to facilitate positioning next to tissue at a treatment site. The size of loop 166 is adjusted so as to lie contiguous with annulus of tissue A at a treatment site, as seen in FIG. 13B. The loop may be collapsible within catheter 162 to facilitate percutaneous delivery and is electrically coupled to RF source 168, which is electrically coupled to reference electrode 170. Loop 166 may be fabricated from nitinol, copper, or any other suitably conductive and ductile material.

[0091] Referring to FIGS. 14A and 14B, a still further alternative embodiment of the apparatus of FIG. 2, and a method of using the embodiment with the introduction technique of FIG. 12, is described. Apparatus 170 comprises catheter 172 and end effector 174. End effector 174 is capable of grabbing and penetrating tissue, as well as delivering RF energy into tissue. End effector 174 comprises jaws 176a and 176b, which are spring-biased against one another to a closed position. By pushing a knob on the handpiece (not shown), the jaws may be actuated to an open position configured to grab tissue at a treatment site. RF energy may then be deposited in the tissue in a monopolar or

bipolar mode. Jaws 176 may optionally be coated with electrically insulating layer I everywhere except in a distal region, such that tissue is only treated at depth, as described hereinabove. End effector 174 has temperature sensor 178 to control power delivered to the tissue, again as described hereinabove.

[0092] With reference to FIG. 14B, a method of using apparatus 170 via a septostomy introduction technique to treat mitral valve regurgitation is described. In particular, jaws 176 of end effector 174 are actuated to engage individual sections of valve annulus A so as to penetrate into the collagenous sublayers and to thermally shrink those sublayers. The procedure may be repeated at multiple locations around the perimeter of annulus A until regurgitation is minimized or eliminated.

[0093] FIGS. 15A and 15B show an alternative end effector for use with apparatus 170 of FIGS. 14. End effector 180 is shown in an open position and in a closed position, respectively, and comprises jaws 182a and 182b. End effector 180 is similar to end effector 174, except that jaws 182 are configured to engage tissue with a forceps grasping motion wherein bent tips 184a and 184b of the jaws are disposed parallel to one another and contact one another when closed.

[0094] With reference now to FIGS. 16-20, apparatus of a second family of embodiments of the present invention are described. These embodiments are provided with an end effector that selectively induces a temperature rise in the chordae tendineae sufficient to cause a controlled degree of shortening of the chordae tendineae, thereby enabling valve leaflets to be properly aligned.

[0095] A preferred use for apparatus of the second family is in treatment of mitral valve regurgitation. Mitral valve regurgitation has many causes, ranging from inherited disorders, such as Marfan's syndrome, to infections and ischemic disease. These conditions affect the macromechanical condition of the mitral valve and prevent the valve from closing completely. The resulting gap in the leaflets of the valve permit blood to regurgitate from the left ventricular chamber into the left atrium.

[0096] Mechanically, the structural defects characterizing mitral valve regurgitation include: (1) the chordae tendineae are too long due to a given

disease state; (2) papillary muscle ischemia changes the shape of the papillary muscle, so that attached chordae tendineae no longer pull the leaflets of the mitral valve completely shut; (3) the annulus of the mitral valve becomes enlarged, resulting in the formation of a gap between the leaflets when closed; and (4) there is an inherent weakness in the leaflets, leaving the leaflets floppy and dysfunctional.

[0097] In accordance with the principles of the present invention, a temperature rise is induced in the support structure of the mitral valve to cause shrinkage that modifies the geometry of the valve to restore proper stopping of blood backflow and thereby regurgitation. This process is depicted in FIGS. 18-20 using the apparatus of FIGS. 16 and 17 to selectively shrink portions of the chordae tendineae, thereby bringing leaflets of the mitral valve leaflets into alignment. Apparatus of the second family may also be used in treatment of aortic valve regurgitation, and in treatment of a variety of other ailments that will be apparent to those of skill in the art.

[0098] Referring to FIG. 16, apparatus 200 comprises catheter 202 and end effector 204. Catheter 204 optionally comprises collapsible and expandable stabilizer 206, configured to stabilize apparatus 200 in a body lumen. Stabilizer 206 may comprise, for example, struts or an inflatable balloon.

[0099] End effector 204 may be collapsible to a delivery configuration within catheter 202, and may expand to a delivery configuration beyond a distal end of the catheter. End effector 204 is configured to engage, heat, and shrink chordae tendineae. Various sources of energy may be used to impart heat to the collagenous tissue and thereby shrink it, including RF energy, focused ultrasound, laser energy, and microwave energy. In addition, chemical modifiers, such as aldehydes, may be used. For laser embodiments, a preferred laser is a continuous wave Holmium:Yag laser, with application of visible or infrared laser energy in the wavelength range of 400 nanometers to 10.6 micrometers.

[0100] With reference to FIGS. 17A-17C, embodiments of end effector 204 are described. In FIG 17A, the end effector comprises a gripping mechanism that carries the heating element. Arms 210a and 210b are opposing and spring-

biased against each other. The arms may be actuated to an open position using a handpiece (not shown) coupled thereto. Arms 210a and 210b may alternatively be vertically displaced with respect to one another to allow the arms to criss-cross and tightly grasp tissue. Heating elements 212 and temperature sensors 214 are attached to the arms. Heating elements 212 may comprise electrodes, acoustic transducers, side-firing laser fibers, radioactive elements, etc. It may be desirable to employ a saline flush with heating elements 212 to prevent coagulation of blood caught between arms 210.

[0101] FIG. 17B shows an embodiment of end effector 204 with fixed, straight arms 220a and 220b. The arms are configured to engage and disengage chordae tendineae simply by being positioned against the tendineae. FIG. 17C shows an embodiment of the end effector having arms 230a and 230b. Multiple heating elements 212 are disposed on arm 230a. When heating elements 212 comprise bipolar electrodes, current flow through the tendineae using the embodiment of FIG. 17C may be achieved primarily along a longitudinal axis of the tendineae, as opposed to along a radial axis of the tendineae, as will be achieved with the embodiment of FIG. 17A. These alternative heating techniques are described in greater detail hereinbelow with respect to FIGS. 19 and 20.

[0102] Referring to FIG. 18, a method of using apparatus of the second family of embodiments to induce shrinkage of chordae tendineae CT is described. Catheter 202 of apparatus 200 is advanced percutaneously, using well-known techniques, through the ascending aorta AA and aortic valve AV into the left ventricle LV, with end effector 204 positioned within the catheter in the collapsed delivery configuration. Stabilizer 206 is then deployed to fix catheter 202 in ascending aorta AA, thereby providing a stationary leverage point.

[0103] End effector 204 is expanded to the deployed configuration distal of catheter 202. The end effector is steerable within left ventricle LV to facilitate engagement of chordae tendineae CT. End effector 204, as well as any of the other end effectors or catheters described herein, may optionally comprise one or more radiopaque features to ensure proper positioning at a treatment site. End effector 204 is capable of moving up and down the chordae tendineae to grab and

selectively singe certain sections thereof, as illustrated in dotted profile in FIG. 18, to selectively shorten chordae tendineae CT, thereby treating valvular regurgitation.

[0104] When energy is transmitted through tissue utilizing one of the embodiments of this invention, the tissue absorbs the energy and heats up. It may therefore be advantageous to equip the end effector with temperature or impedance sensors, as seen in the embodiments of FIGS. 17, to output a signal that is used to control the maximum temperature attained by the tissue and ensure that the collagen or other tissues intended to be shrunk are heated only to a temperature sufficient for shrinkage, for example, a temperature in the range of 45°C-75°C, and even more preferably in the range of 55°C-65°C. Temperatures outside this range may be so hot as to turn the tissue into a gelatinous mass and weaken it to the point that it loses structural integrity. A closed loop feedback system advantageously may be employed to control the quantity of energy deposited into the tissue responsive to the output of the one or more sensors. In addition, the sensors may permit the clinician to determine the extent to which the cross-section of a chordae has been treated, thereby enabling the clinician to heat treat only a portion of the cross-section.

[0105] This technique is illustrated in FIGS. 19 and 20, in which alternating bands, only a single side, or only a single depth of the chordae is shrunk to leave a “longitudinal intact fiber bundle.” This method may be advantageous in that, by avoiding heat treatment of the entire cross section of the chordae, there is less risk of creating mechanical weakness.

[0106] FIGS. 19A-19C depict a method of shrinking a section of chordae tendineae CT in a zig-zag fashion using the embodiment of end effector 204 seen in FIG. 17C. In FIG. 19A, the tendineae has an initial effective or straight length L_1 . Arms 230 engage chordae tendineae CT, and heating elements 212 are both disposed on the same side of the tendineae on arm 230a. The heating elements may comprise bipolar electrodes, in which case the path of current flow through tendineae CT is illustrated by arrows in FIG. 19A.

[0107] Collagen within the tendineae shrinks, and chordae tendineae CT assumes the configuration seen in FIG. 19B. Treatment zone Z shrinks, and the tendineae assumes a shorter effective length L_2 . Treatment may be repeated on the opposite side of the tendineae, as seen in FIG. 19C, so that the tendineae assumes a zig-zag configuration of still shorter effective length L_3 . In this manner, successive bands of treatment zones Z and intact longitudinal fiber bundles may be established.

[0108] An additional pair of bipolar electrodes optionally may be disposed on arm 230b of the end effector to facilitate treatment in bands on opposite sides of chordae tendineae CT. The depth of shrinkage attained with apparatus 200 is a function of the distance between the electrodes, the power, and the duration of RF energy application. If, laser energy is applied, the wavelengths of energy application may be selected to provide only partial penetration of the thickness of the tissue. For example, continuous wave Holmium:YAG laser energy having a wavelength of 2.1 microns penetrates a mere fraction of a millimeter and may be a suitable energy source.

[0109] FIGS. 20A-20C illustrate additional shrinkage techniques. Intact chordae tendineae CT is seen in FIG. 20A. FIG. 20B demonstrates shrinkage with apparatus 200 only on one side of the chordae, using the technique described with respect to FIGS. 19. FIG. 20C demonstrates shrinkage with, for example the end effector of FIGS. 17A or 17B, wherein, for example, bipolar current flows across the tendineae and treats the tendineae radially to a certain preselected depth. When viewed in cross-section along sectional view line C-C of FIG. 20A, chordae tendineae CT has an intact longitudinal fiber bundle core C surrounded by treatment zone Z.

[0110] With reference to FIGS. 21-22, apparatus of a third family of embodiments of the present invention are described. These embodiments are provided with an end effector comprising a mechanical reconfigurer configured to engage a longitudinal member, such as the chordae tendineae. The reconfigurer forces the longitudinal member into a tortuous path and, as a result, reduces the member's effective overall or straight length.

[0111] Referring to FIGS. 21A and 21B, apparatus 300 comprises catheter 302 and end effector 304. End effector 304 comprises mechanical reconfigurer 306, adapted to mechanically alter the length of a longitudinal member, for example, chordae tendineae. Reconfigurer 306 comprises a preshaped spring fabricated from a shape memory alloy, for example, nitinol, spring steel, or any other suitably elastic and strong material. Reconfigurer 306 is preshaped such that there is no straight path through its loops. Overlap between adjacent loops is preferably minimized. The shape of reconfigurer 306 causes longitudinal members, such as chordae tendineae, passed therethrough to assume a zig-zag configuration and thereby be reduced in effective length. Reconfigurer 306 is collapsible to a delivery configuration within catheter 302, as seen in FIG. 21A, and is expandable to a deployed configuration, as seen in FIG. 21B. The reconfigurer optionally may be selectively detachable from catheter 302.

[0112] With reference to FIGS. 22A and 22B, a method of using apparatus 300 to mechanically shorten chordae tendineae CT is described. Apparatus 300 is advanced to the chordae tendineae, for example, using the technique described hereinabove with respect to FIG. 18. End effector 304 is then expanded from the delivery configuration seen in FIG. 22A to the deployed configuration of FIG. 22B. Mechanical reconfigurer 306 regains its preformed shape, and chordae tendineae CT is passed through a tortuous path that reduces its effective length, thereby treating valvular regurgitation. Reconfigurer 306 may then be detached from apparatus 300 and permanently implanted in the patient, or the reconfigurer may be left in place for a limited period of time to facilitate complementary regurgitation treatment techniques.

[0113] Other embodiments of the third family in accordance with the present invention will be apparent to those of skill in the art in light of this disclosure.

[0114] Referring now to FIG. 23, apparatus in accordance with the present invention is described that may be used as either an embodiment of the first family or of the second family. Apparatus and methods are provided for noninvasively coagulating and shrinking scar tissue around the heart, or valve

structures inside the heart, using energy delivered via high intensity, focused ultrasound. Apparatus 350 comprises catheter 352 and end effector 354. End effector 354 comprises ultrasonic transducer 356 and focusing means 358, for example, a lens. Focused ultrasound is propagated and directed with a high level of accuracy at the chordae CT, the annuluses A of the valves or at a section of bulging wall of the heart, using, for example, echocardiography or MRI for guidance. As with the previous embodiments, the shrinkage induced by energy deposition is expected to reduce valvular regurgitation. Apparatus 350 may also be used to reduce ventricular volume and shape, in cases where there is bulging scar tissue on the wall of the left ventricle LV secondary to acute myocardial infarction.

[0115] Alternatively, various mechanical valve resizing systems and methods may be used in conjunction with the apparatus and methods discussed above. Optionally, the various mechanical valve resizing systems and methods, as discussed below, may be used as a stand-alone system. These mechanical resizing systems may generally entail the positioning, deployment, and securing of one or more clips to bring the annular edges of a valve, e.g., a heart valve, or opening together to correct for valvular regurgitation. This would typically result in the reduction of the effective diameter of the valve or opening. The clip is preferably made of superelastic or shape memory materials, e.g., Nickel-Titanium alloys, because of the ability of these types of materials to be easily formed, e.g., by annealing, into desirable geometries. Such materials are very strong and have the ability to be constrained into a reduced diameter size for deployment as well as being capable of providing a permanent compressive spring force.

[0116] The variations of clip geometries described herein may be manufactured in several ways. One method involves securing a wire, band, or other cross-sectioned length, preferably made of a superelastic or shape memory material, to a custom forming fixture (not shown). The fixture preferably has a geometry similar to the valve or opening where the completed clip is to be placed and the fixture preferably has a diameter which is smaller than the diameter of the valve or opening. The fixture diameter may be determined by the amount of

closure by which the valve or opening may need to be closed or approximated to reduce or eliminate valvular regurgitation. The fixture, with a constrained clip placed thereon, may be subjected to a temperature of about 500° to 700° F preferably for a period of about 1 to 15 minutes. Additional details about the processing and performance of superelastic and shape memory materials may be seen in U.S. Patent No. 5,171,252 to Friedland, which is incorporated herein by reference in its entirety. The fixture and clip may then be removed and subjected to rapid cooling, e.g., quenching in cold water. The clip may then be removed from the fixture and the ends of the clip may be trimmed to a desired length. The trimmed ends may also be formed into a sharpened point by, e.g., grinding, to facilitate piercing of the tissue.

[0117] FIG. 24A shows a variation of a valve resizing device in expandable grid 360. Grid 360 is shown as having alternating member 362 formed of a continuous alternating length while forming several anchoring regions 364, which may be radiused. The number of alternating members (and number of resultant anchoring regions 364) formed may be determined by a variety of factors, e.g., the geometry of the valve to be resized or the amount of spring compression required. Grid 360 is preferably made of a shape memory alloy, as discussed above. The terminal ends of alternating member 362 preferably end in anchoring ends 366. Anchoring ends 366 may define a range of angles with the plane formed by alternating member 362, e.g., 45°, but is preferably formed perpendicular to the plane. Ends 366 may be formed integrally from alternating member 362, which may first be cut to length, by reducing a diameter of ends 366 to form, e.g., a barbed end or double-barbed end as shown in the figure and in the detail view. Alternatively, anchoring ends 366 may be formed separately and attached to the ends of alternating member 362 by, e.g., adhesives, welding, or scarf joints. The ends 366 are shown in this example as a double-barbed anchoring fastener, but generally any type of fastening geometry may be used, e.g., single-barbs, semi-circular or triangular ends, screws, expandable locks, hooks, clips, and tags, or generally any type of end geometry that would facilitate

tissue insertion yet resist being pulled or lodged out. Also, sutures and adhesives, as well as the barbs, may be used to fasten grid 360 to the tissue.

[0118] Another variation on a grid-type device is shown in FIG. 24B as expandable mesh 368. In this variation, several individual interwoven members 370 may be woven together to form a continuous mesh. Members 370 may be either welded together or loosely interwoven to form expandable mesh 368. In either case, the geometries of both expandable grid 360 and mesh 368 are formed to preferably allow a compressive spring force yet allow a relative degree of expansion once situated on the valve or opening.

[0119] To maintain grid 360 or mesh 368 over the valve or opening, fasteners located around the valve or opening are preferably used for anchoring grid 360 or mesh 368. Fasteners are preferably made of a biocompatible material with relatively high strength, e.g., stainless steel or Nickel-Titanium. Biocompatible adhesives may also be used. A variation of such a fastener is shown in FIG. 25A. Anchor 372 is shown having a barbed distal end 374 for piercing tissue and for preventing anchor 372 from being pulled out. Shown with a double-barb, it may also be single-barbed as well. Stop 376, which is optional, may be located proximally of distal end 374 to help prevent anchor 372 from being pushed too far into the tissue. A protrusion, shown here as eyelet 378, is preferably located at the proximal end of anchor 372 and may extend above the tissue surface to provide an attachment point. Grid 360 or mesh 368 may be looped through eyelet 378 or they may be held to eyelet 378 by sutures or any other conventional fastening methods, e.g., adhesives.

[0120] Another variation on fasteners is shown in FIG. 25B. Here, locking anchor 380 is shown with distal end 382 having pivoting or butterfly-type lock 384. Stop 386 is preferably located proximally of distal end 382 and protrusion (or eyelet) 388 is preferably located at the proximal end of locking anchor 380. In use, pivoting lock 384 may be retracted against the shank of anchor 380 while being pushed into the tissue. When anchor 380 is pulled back, pivoting lock 384 may extend outwardly to help prevent anchor 380 from being pulled out of the tissue.

[0121] FIG. 26 shows a cross-sectional superior view of, e.g., human heart section 390, with the atrial chambers removed for clarity. Heart tissue 392 is seen surrounding tricuspid valve 400 and bicuspid or mitral valve 402. Sectioned ascending aorta 394 and pulmonary trunk 396 are also seen as well as coronary sinus 398 partially around the periphery of heart section 390. An example of expandable grid 360 in a deployed configuration is shown over tricuspid valve 400. Grid 360 may be placed entirely over valve 400 and anchored into heart tissue 392 by anchors 404, which may be of a type shown in FIGS. 25A or 25B, at anchoring regions 364. Once grid 360 is in place, it may impart a spring force which may draw the opposing sides of valve 400 towards one another, thereby reducing or eliminating valvular regurgitation.

[0122] Another variation on a biasing clip device is shown in FIGS. 27A and 27B. FIG. 27A shows circumferential clip 406 having opposing members 408. This clip variation, preferably made of a shape memory alloy, e.g., Nickel-Titanium alloy, may be inserted into the tissue surrounding a valve. This clip may surround the periphery of the valve and provide an inwardly biased spring force provided by opposing members 408 to at least partially cinch the valve. The variation in FIG. 27A preferably surrounds about 50% to 75% of the valve circumference. The variation of clip 410 is shown in FIG. 27B with opposing members 412. Here, the clip may be made to surround at least about 50% of the valve circumference. FIG. 28 again shows the cross-sectional superior view of heart section 390 except with circumferential clip 406 placed in the tissue 392 around valve 400. As shown, opposing members 408 preferably provide the inwardly biased spring force to at least partially cinch valve 400.

[0123] A further variation of the clip is shown generally in FIGS. 29A and 29B. A side view of valve clip 414 is shown in FIG. 29A having anchoring members 416 on either end of clip 414. FIG. 29B is an end view of valve clip 414. FIGS. 30A and 30B likewise show another variation of valve clip 418 with curved anchoring members 420 on either end of the clip. This variation of valve clip 418 shows the addition of curved central region 422 which may be located near or at the center of clip 418. Region 422 may be incorporated to act as a

stress-relieving mechanism by allowing clip 418 to bend or pivot to a greater degree about region 422 than clip 418 normally would. This may also allow for greater adjustability when placing clip 418 over a valve. FIG. 30B shows an end view of the clip.

[0124] Another variation is seen in FIGS. 31A to 31D. FIG. 31A shows a top view of arcuate valve clip 424. Clip 424 preferably has an arcuate central member 426, which is shown as a semicircle having a radius, R . Central member 426 may serve to act as a stress-relieving member, as described above, and it may also be designed to prevent any blockage of the valve by clip 424 itself. Thus, radius, R , is preferably large enough so that once clip 424 is placed over the valve, central member 426 lies over the valve periphery. FIG. 31B shows a side view of the clip. This view shows anchoring members 430 attached by bridging members 428 on either end to central member 426. FIG. 31C shows an end view of the clip where the anchoring members 430 and central member 426 are clearly shown to lie in two different planes defining an angle, α , therebetween. The angle, α , may vary greatly and may range from about 60° to 120° , but is preferably about 90° for this variation. Finally, FIG. 31D shows an isometric view of clip 424 where the biplanar relationship between anchoring members 430 and central member 426 can be seen.

[0125] The curved anchoring members above are shown as being curved in a semi-circle such that they face in apposition to one other. But any geometry may be used, e.g., arcs, half-ellipses, hooks, V-shapes or triangles, and generally any type of end geometry that would facilitate tissue insertion yet resist being pulled or lodged out.

[0126] The shape of the clip itself may range from a wide variety of geometries. Such geometries may include circles, semi-circles, rectangles, triangles, or any combinations thereof. FIGS. 32A and 32B show a top and side view, respectively, of valve clip 432a and anchoring members 434a where the entire clip 432a preferably curves in an arcuate manner. FIGS. 33A and 33B show a top and side view, respectively, of clip 432b with anchoring members 434b where clip 432b is in a triangular shape. FIGS. 34A and 34B show a top and

side view, respectively, of clip 432c with anchoring members 434c where clip 432c is in a rectangular shape. FIGS. 35A and 35B show a top and side view, respectively, of clip 432d with anchoring members 434d where clip 432d is a looped section. Likewise in FIGS. 36A and 36B show a top and side view, respectively, of clip 432e with anchoring members 434e where clip 432e has a curved section, which may act as a stress-relieving member. These various clip geometries are presented as examples and in no way limit the scope of the invention.

[0127] Any of the above-described clips or any other clip geometry in the spirit of this invention may be coated with a variety of substances. For example, a clip may be coated with a hydrophilic (which may be used, e.g., for surface lubricity), anti-thrombosis agent, therapeutic agent, or any other drug coating to prevent, e.g., thrombosis, or to act as a drug delivery mechanism. Such drug coatings may be applied during the clip manufacture or just prior to deployment. Also, the clips may be made to become more radiopaque by coating them with, e.g., Nickel-Titanium alloy, Platinum, Palladium, Gold, Tantalum, or any other biocompatible radiopaque substance. Such a coating could be applied, e.g., by sputter coating or ion deposition. Moreover, the coating is preferably applied in a thin enough layer such that it would not affect the physical properties of the clip material.

[0128] The clip may be delivered and placed over or around the valve using a variety of different methods, e.g., endoscopically, laparoscopically, or through other conventional methods such as open-heart surgery. A preferable method and apparatus is to deliver the clip through the vasculature using a delivery catheter and/or guidewire. FIG. 37 shows a variation of such a catheter in the cross-sectioned view of a distal section of delivery catheter 436. Catheter body 438, which may comprise an outer layer of catheter section 436, may be comprised of a variety of materials, e.g., polyimide, polymeric polyolefins such as polyethylene and polypropylene, high density polyethylene (HDPE), etc. and is preferably lubricious to allow easy traversal of the vasculature. Catheter body 438 preferably has delivery lumen 440 defined throughout the length of catheter

section 436 and may terminate at the distal tip in delivery port 442. Delivery port 442 may be an open port and it may be sealable during delivery when catheter section 436 traverses the vasculature. At the distal most end of section 436, distal tip 443 may be placed with delivery port 442 defined therethrough. Distal tip 443 may be metallic, e.g., Nickel-Titanium alloy, Platinum, Palladium, Gold, Tantalum, etc. to provide radiopacity for visualization by, e.g., a fluoroscope, CT, or PET, and is preferably rounded to be atraumatic to the vasculature. Catheter section 436 may alternatively use a radiopaque marker band (not shown) either alone or in addition to tip 443 to further aid in visualization.

[0129] Clip 444 may be disposed in lumen 440 within catheter section 436; as seen, clip 444 is preferably in a compressed configuration to fit within lumen 440 during delivery. The clip 444 may be loaded into catheter section 436 through delivery port 442, or alternatively, through the proximal end of delivery lumen 440 and advanced towards the distal end of catheter section 436. Reinforced liner 446 may surround the area where clip 444 is loaded to allow structural reinforcement to catheter body 438. Liner 446 may also allow constraintment of clip 444 while allowing forward movement of the clip 444 during deployment. Liner 446 may be made from a thin-walled superelastic or shape memory tube and may also have a lubricious coating to reduce the amount of force required for deployment of clip 444. Catheter section 436 may be guided within the vasculature via a conventional guidewire (not shown), or it may be steered through the vasculature via steering lumen 452 which may contain steerable components, e.g., wire 453, disposed within to steer catheter section 436. Wire 453 may be a pull-wire, leaf spring, or other steering-type device.

[0130] Once catheter section 436 has reached the target site, clip 444 may be advanced through delivery port 442 by plunger 448. Plunger 448 is preferably attached to a distal end of stylet 450, which may run through the full length of catheter body 438 to allow manipulation from the proximal end. Plunger 448 may be advanced towards the distal end of catheter section 436 to urge clip 444 out of delivery port 442 by manipulating the proximal end of stylet 450. Stylet 450 may be advanced manually like a guidewire, or by attaching it to an advancement

mechanism, e.g., a thumb-slide. Stylet 450 may also be passed through a hemostatic valve located within catheter body 438, either at a distal or proximal end, to prevent backflow into lumen 440 during insertion and delivery through the vasculature. The advancement mechanism, discussed further below, may be controlled by an indexed linear movement mechanism, e.g., a screw, ratchet, etc., located on a handle at the proximal end of catheter body 438. Once plunger 448 and stylet 450 is advanced completely, clip 444 may be urged completely through delivery port 442, where it may then expand or form its deployed configuration.

[0131] FIG. 38 shows catheter section 436 with another compressed variation of clip 454. Here, clip 454 may be compressed into a “U” or “V” shape for delivery and deployed in the same manner by plunger 448 and stylet 450 through delivery port 442, as discussed above. This variation enables the ends of clip 454 to be deployed simultaneously; however, this variation may also require a larger delivery port 442 than the variation shown in FIG. 37.

[0132] FIG. 39 shows a further variation of the distal end of deployment catheter section 456. This variation shows catheter body 458 with delivery lumen 460 terminating in distal tip 461, much like the variations shown above. But here, distal tip 461 does not have a delivery port defined through it, rather delivery port 462 is preferably defined along a distal length of catheter body 458 proximally of distal tip 461. Clip 464 may be any of the variational shapes described above but is shown here in a compressed arcuate shape. Clip 464 may be held within catheter section 456 by an external constraining sheath or it may be held simply by friction fitting clip 464 within delivery port 462. Catheter section may be steered to the desired target site via steering lumen 468 and once in position, deployment stylet 466 may be urged towards the distal end of section 456 in much the same manner as described above. However, stylet 466 is preferably angled at its distal tip to facilitate pushing clip 464 out through delivery port 462.

[0133] FIGS. 40A and 40B show a top and side view, respectively, of an example of catheter handle 470 which may be used to advance the clip into position over a valve or opening. This variation shows handle 470 with distal end 472, where the catheter is preferably attached, and the linear advancement

mechanism, shown here as thumb-slide 474. Thumb-slide 474 may be advanced in advancement slot 476 towards distal end 472 to urge the plunger and stylet. Within handle 470, the advancement of thumb-slide 474 may be controlled by an indexing mechanism, e.g., a screw, ratchet, or some type of gear, which may allow the proximal and distal movement of the thumb-slide 474 through slot 476.

[0134] Delivering and placing the clip over the desired tissue, valve, or opening may be accomplished by several different methods. As shown in FIG. 41A, one exemplary method is to introduce deployment catheter 478 into the coronary vasculature through, e.g., the jugular vein, and into the superior vena cava SVC. From there, tricuspid valve TV may be treated or the mitral valve MV may be treated by having catheter 478 penetrate the atrial septum AS using a septostomy procedure, as discussed above. Once septum AS is perforated, catheter distal end 480 may be inserted into the left atrium LA and brought into position over the mitral valve MV. Catheter distal end 480 may be positioned over mitral valve MV by tracking its position visually through a fluoroscope or other device by using the radiopaque distal tip (as described above) or via a radiopaque marker band or half-marker band 486. As shown, distal end 480 may be brought into contact against or adjacent to one side of the annulus of tissue A. The plunger may be advanced (as described above) to then urge a first end of clip 484 out through delivery port 482 and into the annulus of tissue A.

[0135] Then, as shown in FIG. 41B, distal end 480 may be moved or steered to the opposite side of the annulus of tissue A after or while the rest of clip 484 is advanced through delivery port 482. The distal end 480 is preferably moved to the opposite side of the mitral valve MV at about 180°, if possible, from the initial contact point to allow for optimal reduction of the diameter of the valve. Once distal end 480 is positioned on the opposing side of the valve, the plunger may then be finally advanced so that the remaining second end of clip 484 exits delivery port 482 and engages the annulus of tissue A.

[0136] The variations described above may incorporate a variety of sensors or transducers in the delivery catheter to ensure adherence or optimal clip performance. For instance, as seen in FIG. 41C sensor/transducer 485, e.g.,

ultrasound, Doppler, electrode, pressure sensor or transducer, etc., may be incorporated into the distal end 480 of the catheter 478. Sensor/transducer 485 may be connected, electrically or otherwise, to a sensor monitor 487, which is preferably located outside the body of the patient and which may be used to record and/or monitor a variety of signals generated from sensor/transducer 485. For example, a pressure sensor may be used as sensor/transducer 485. This pressure sensor may then be used to quantify the treatment effectiveness before catheter 478 is withdrawn. In another variation, sensor/transducer 485 (in this case, used as, e.g., a transducer) may be used to deliver energy, e.g., RF, electrical, heat, etc., to enhance the treatment effectiveness, in which case monitor 487 may be an electrical or RF power source.

[0137] Distal end 480 may also incorporate a grasping and/or releasing mechanism (not shown) to aid in clip release and implantation. Such a mechanism may be incorporated on the plunger or stylet, or a separate catheter may be inserted in conjunction with catheter 478. The grasping and/or releasing mechanism may also be used to temporarily provide an electrical connection to the clip.

[0138] In a further variation for delivering and placing the clip, it may be deployed through one or more delivery ports located in the side of the catheter rather than from the distal end. Delivering from the catheter side may be accomplished in much the same manner as described for FIGS. 41A-41C above. Alternatively, a catheter may be inserted into the coronary vasculature, particularly the coronary sinus, via the aorta to deliver the clip. A cross-sectional superior view of mitral valve opening 488 of mitral valve 402 of a patient's heart is seen in FIG. 42A. Delivery catheter 490 may be inserted into the coronary sinus 398 and positioned adjacent to mitral valve 402 such that delivery ports 492a, 492b, 492c are preferably facing in apposition to mitral valve 402. Although three delivery ports are shown in this example, one to any number of desired delivery ports may be used. Delivery ports 492a, 492b, 492c are preferably located proximally of distal end 494 and the orientation of the ports

may be maintained against mitral valve 402 by the use of an orientation marker 496, which may be, e.g., a half-marker.

[0139] Once proper orientation has been determined, a first clip 498a, which may be compressed in catheter 490 may be urged out of delivery port 492a by a plunger and stylet, as described above or twisted out, and pushed through a wall of the coronary sinus 398 and through the adjacent heart tissue 392, as shown in FIG. 42B. The clips are preferably made of a superelastic or shape memory alloy, e.g., Nickel-Titanium alloy (e.g., nitinol), and are preferably made to expand as it exits catheter 490. Accordingly, clip 498a may be pushed until the farthest anchoring member of clip 498a is in contact with and enters the edge of valve 402 farthest from catheter 490. As clip 498a finally exits delivery port 492a, the anchoring member may exit and then engage the edge of valve 402 closest to catheter 490. This procedure may be repeated for several clips, as seen in FIG. 42C, where first and second clip 498a, 498b, respectively, are shown to have already exited and engaged the tissue surrounding valve 402. FIG. 42D shows the final engagement of third clip 498c having exited delivery port 492c and engaged the tissue surrounding valve 402. Once the clips are in place, the compressive spring force of the clips may aid in drawing the opposing sides of valve 402 together, thereby drawing or cinching opening 488 close and reducing or eliminating the occurrence of valvular regurgitation through the valve. The use of three clips is merely exemplary and any number of desired or necessary clips may be used.

[0140] FIGS. 43A and 43B show the valve of FIGS. 42A-42D and a side view of the valve, respectively. FIG. 43A shows another example of arcuate clips 500a, 500b, as described in FIGS. 31A-31D, engaged to mitral valve 402. Arcuate clips 500a, 500b are designed such that the curved region of each clip is preferably opposite to each other in order to keep opening 488 unobstructed. FIG. 43B shows a side view of valve 402 in annulus 502. Clips 500a, 500b are preferably engaged to the tissue surrounding annulus 502, e.g., to annulus walls 504.

[0141] All of the above mentioned methods and apparatus may be delivered not only intravascularly through catheters, but also through conventional procedures such as open-heart surgery. Moreover, all of the above mentioned methods and apparatus may also be used in conjunction with flow-indicating systems, including, for example, color Doppler flow echocardiography, MRI flow imaging systems, or laser Doppler flow meters. Application of energy from the end effector may be selected such that regurgitation stops before the procedure is completed, as verified by the flow-indicating system. Alternatively, the procedure may be “overdone” to compensate for expected tissue relapse, without compromising the ultimate outcome of the procedure.

[0142] Additionally, all of the foregoing apparatus and methods optionally may be used in conjunction with ECG gating, thereby ensuring that tissue is at a specified point in the cardiac cycle before energy is deposited into the tissue. ECG gating is expected to make treatment more reproducible and safer for the patient.

[0143] Although preferred illustrative embodiments of the present invention are described above, it will be evident to one skilled in the art that various changes and modifications may be made without departing from the invention. For instance, variations of the present invention may be used as permanent or temporary localized tissue retracting devices. Moreover, modified variations may also be used to mechanically expand or dilate tissue, e.g., for use in maintaining open nasal passages. It is intended in the appended claims to cover all such changes and modifications that fall within the true spirit and scope of the invention.